Design of the RIA Fragment Separators

B.M. Sherrill, D.J. Morrissey, O. Tarasov
National Superconducting Cyclotron Laboratory

Preliminary design work has begun on the RIA fragment separators, yet there are a number of significant R&D tasks that remain. The basic fragment separator layout is needed to plan the civil layout and the placement of the gas stopping station and high-energy experimental areas. The design will also set the specifications for the fragment separator magnets. This is a critical issue related to whether superconducting or normal magnets are used. Whichever technology is chosen, these magnets must be radiation resistant and pose a potentially significant R&D task. The separator specifications also, in principle, impact on the LINAC specifications. The yield of a given radioactive species depends on the primary beam energy and fragment separator acceptance. Higher acceptance separators imply that lower LINAC top energy is necessary. Likewise, if sufficient higher order optical designs can not be found, then efficiency could be gained by increasing the top energy of the RIA LINAC. The design will also be necessary to know the constraints placed on the beam dump and catcher system for collecting unused fragments.

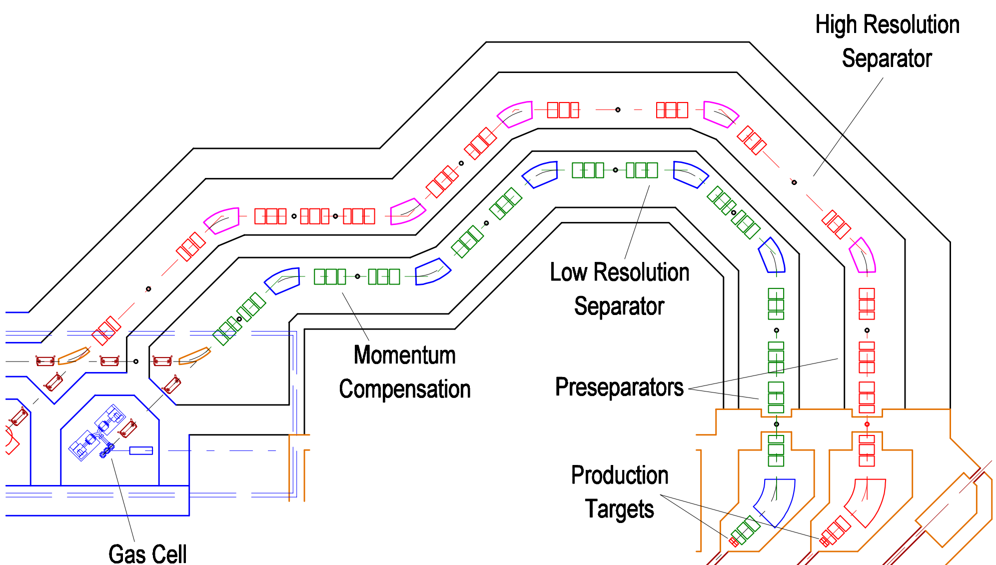

Figure 1. A possible baseline layout of the fragment separation area is shown. Up to 400kW of primary beam strikes the production target. Two fragment separators can be used to deliver separated fragments to experimental areas. Each separator would consist of two stages of separation. A pre-separator would be used to collect the primary beam and unwanted fragments and the second stage separator would provide the final purification.

Two separators are envisioned for RIA [i]. One would deliver beams to a high-energy experimental area and could be very similar to the A1900 separator now operating at the NSCL. The second would deliver beams to an ion-catching station where the ions are slowed, thermalized, extracted, and sent to the post accelerator. The ion-catching station would use high-purity helium gas to stop the ions so that they remain charged and can be extracted quickly in a nearly chemically independent fashion. A momentum compensation section follows the second separator to reduce the range distribution of ions and allow most of the desired ions to be stopped in a reasonable gas volume [ii]. The overall layout of the fragment separation area is shown in Figure 1. This layout has the advantage that the high acceptance separator can provide beams to either the gas stopping station or the high-energy area.

There is considerable experience at the NSCL in the design of fragment separators. The A1200 fragment separator was designed and built at the NSCL in the late 1980s using the existing beam line magnets. The use of these magnets limited the acceptance to 3% in momentum and a solid angle of 1 msr. It was the first separator that could deliver beams to all experimental areas and was used in 60% of the experimental program. In 2001 the A1900 fragment separator was commissioned. This device was also designed and built at the NSCL and was optimized to have nearly 100% collection efficiency for fragments from the MSU Coupled Cyclotron Facility. It works as designed and will serve as a model and testing ground for the RIA separators.

Much of the preliminary design work has gone into code development to allow various fragment separator configurations to be evaluated. The program LISE (written the O. Tarasov and D. Bazin of the NSCL) has been modified to allow a block structure. This is necessary to model the separation, momentum compression and gas stopping process. The most up to date energy loss, charge state and straggling data has been incorporated. We still need to do extensive evaluation of the code. Addition needs are to add fission as a production mechanism and to develop a Monte Carlo version to allow secondary reactions to be investigated. LISE is an essential tool for the design of the RIA fragment separators. It will also be a useful tool for experimenters to plan their experiment. LISE is currently extensively used for this purpose.

1) Separator Specifications

The initial design goals for the separators were given in the ISOL task force report. These goals are ambitious, yet are required to achieve the maximum output of the facility for 400 MeV/u beams. In order to collect more than 50% of the fragments from the fragmentation and fission of Uranium at 400 MeV/nucleon, the fragment separators should have a solid angle of 10 msr and a momentum acceptance of 12%. The maximum rigidity should be 10 T-m to allow all neutron rich fragments to be collected, although 8 T-m would be workable with a significant loss in intensity for some of the most neutron rich fragments. For example, given the highest possible beam energy for ^{48}Ca at RIA, the yield of ^{41}Al could be increased by a factor of 2 in going from an 8 Tm to a 10 Tm limit. A higher momentum acceptance would be desirable as it would increase the fission yield by nearly 50% in going from 12% to 18% acceptance. However it may be difficult to achieve this large acceptance. The other complication is that it will increase, significantly the problems in removing the primary beam and its charge states.

2) Production Targets

The targets needed for the production of fast beams at RIA have several significant constraints. To reduce the effect of geometric aberrations in the fragment separator that will limit collection efficiency in the gas-stopping cell and separation quality, the beam spot diameter should be <1 mm. Given that approximately 20% of the primary beam power is lost in the production target, the power densities in the target are extremely high, up to 500 kW/cm^3 (assuming a 400 kW primary beam). For projectile fragmentation, the ideal target has a low Z and hence has more atoms/cm^2 than a higher Z target, however, it is possible that for certain special cases, e.g. for Coulomb breakup, a higher Z target would be preferable. Prototype work is underway at ANL [iii] for a windowless liquid lithium target suitable for heavy beams.

The liquid lithium target planned for use with the Uranium beam may not be appropriate for lighter beams. Due to the low density of lithium, the target will become many centimeters thick and the image aberrations associated with this thick target may not be acceptable. Hence, unless a separator can be designed with a large depth of field (not likely since there is also the desire for a large solid angle to collect fission fragments) hybrid lithium-beryllium target designs will be needed.

3) Fragment Separators

Baseline separator designs have been made for a high acceptance separator for the gas stopping station and a higher resolution separator to deliver beams to the fast beam area. The design goals are to achieve 10 T-m bending power with a 12% momentum acceptance and a 10 msr solid angle for the high efficiency separator and 6% momentum acceptance and 8 msr for the higher resolution separator. A full design of both separators that includes all limitations imposed by radiation hard magnets and the radiation fields of the beams dumps has not yet been made. The higher acceptance separator can accommodate a large acceptance (and hence more contaminants) since the differing unwanted beams will stop at different depths in the ion catcher. A schematic layout of the fragment separators is shown in Figure 1. A more detailed optical design and layout for the high-acceptance separator is shown in Figure 2.

Given the high radiation fields produced by 100 to 400 kW primary beams it is likely that the separators should have two stages: a pre-separator that removes most of the primary beam and other intense fragments, and the main separator that selects the ions of interest. Two stages of separation also significantly reduce impurity ions and most likely result in higher extraction efficiency for the gas-stopping cell. Also the wedge can be a significant source of secondary ions and can hence the one should limit the number of ions hitting this location.

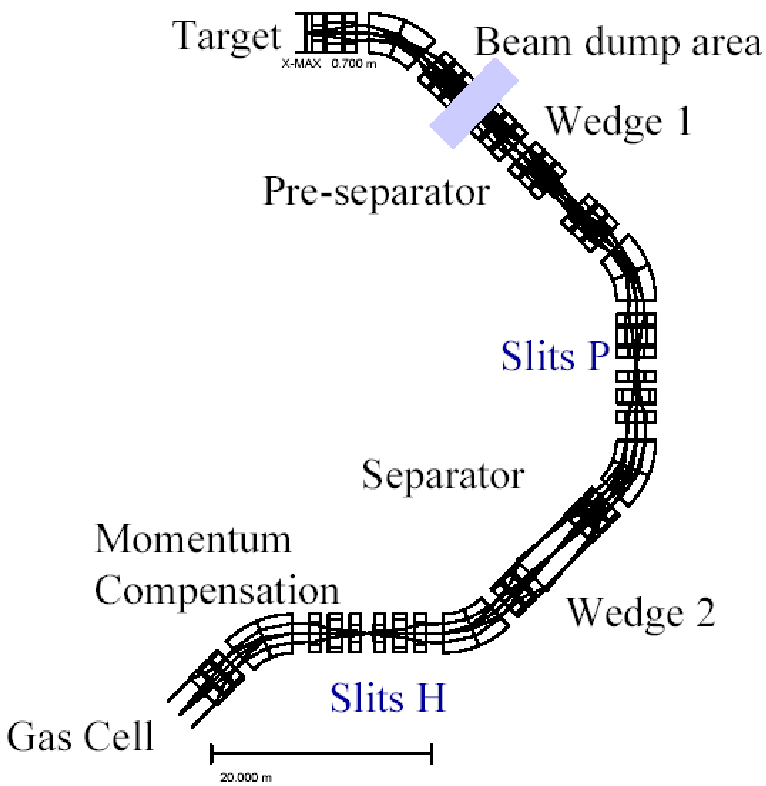

Figure 2: First order optical layout of a possible RIA high-acceptance separator with an acceptance of 10 msr and a momentum acceptance of 12%. A first focus occurs directly after the first dipole, where the beam and unwanted fragments can be collected.

A pre-separator will allow the removal of the primary beam and most unwanted fragments from the ions of interest. This reduces the radiation field outside the production area and also secondary interactions of ions (in the wedge, for example) that can cause significant background. Two stages of separation will significantly reduce the number of contaminant fragments that would pass into the gas cell [iv]. The level of contaminants passing through the gas cell must not be too high and the reduction of unwanted ions will lead to higher extraction efficiencies. Ideally, the pre-separator would also allow the collection of unused isotopes for other applications. The separator optics will have a focus after the first dipole and the beam dump would be placed at this location. This area would also serve as a location for isotope recovery. A shielding wall separates the first part of the separator from the rest of the system. The whole system is achromatic and would operate as a standard fragment separator.

A full simulation of the radiation fields and power deposition has not yet been performed, but is essential. Significant R&D may be required to construct a 100 to 400 kW beam dump that can catch ions such as uranium. In addition, several percent of the primary beam may interact in the production target and produce kiloWatts of other fragments that must be collected. The expected primary beam spot size at the location of the primary beam dump is 5 cm^2 in area and the stopping distance is as low as 1 cm. This results in a high power density and beam stop options need to be investigated. R&D on many aspects of the beam dump design is necessary.

The high-resolution separator would be very similar to the design of the A1900 at the NSCL. Considerable experience exists at the NSCL in the design and operation of this type of fragment separator and there are no significant challenges associated with meeting the desired 8 msr solid angle and 6% momentum acceptance. A higher momentum acceptance would increase the yield of a given fragment, but would also significantly increase the amount of contaminant ions. The current specification is set as a compromise between purity and rate.

4) Gas Stopping Station

The ideal catcher material is high-purity helium gas. The ionization potential of He is such that all ions stopping in pure gas will remain ionized and can be extracted, as discussed in other contributions to this workshop. The goal is to stop as many ions as possible in the gas. This can be done by momentum compression of the fragments in a final dispersive stage in the fragment separator as shown in figure 2. The range distribution of fragments is determined by the range straggling of ions and the momentum spread of the beam. The range straggling is a function of energy and generally the momentum compression is done at an optimum energy for each fragment. In order to have the momentum compression limit match the range straggling limit, the optical resolution of the system must be in the range of 0.1%. This is a stringent limit and requires a very good degree of higher order optical corrections. This is a challenge to achieve for the large acceptances desired for the RIA separators, and requires further R&D.

5) Conclusions and R&D Tasks

Finalization of the baseline separator designs for RIA is a high priority R&D activity. The designs will impact the facility layout and may impact on the desired top energy of the machine. The designs also directly impact the performance of RIA and if higher order corrected solutions can be found there are potentially factors of 2 increase are possible in the yield of rare isotopes. A significant issue is the collection of the primary beam and unwanted fragments. The design presented here allows the beam to be collected as early in the facility as possible. However, further optimization and investigation of the space required for the beam dumps is necessary. In general, it is essential to make a detail study of the radiation fields in the separator and the impact these have on the design. The radiation resistance of the separator magnets must be considered in detail.

i. B.M. Sherrill, “Overview of the RIA Project”, NIM B204 (2003) 765.
ii. H. Geissel e al., “Ions penetrating through ion-optical systems and matter”, NIM A 282 (1989) 247.
iii. J. A. Nolen et al., “Development of windowless liquid lithium targets for fragmentation and fission of 400 kW uranium beams”, NIM B204 (2003) 293.
iv. H. Geissel et al., “The super FRS project at GSI”, NIM B204 (2003) 71.